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Effect of Parkland *Ziziphus Spina-Christi* and *Mangifera Indica* Trees on Selected Physicochemical Properties of Soil in Sofi District, Harari Region, Ethiopia

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ABSTRACT

Information regarding the effects of multipurpose tree species in parkland agroforestry practice on soil conditions in Ethiopia is very scarce. The study was intended to investigate the effects of parkland Mangifera indica and Ziziphus spina-christi trees species on the selected physicochemical properties of soil within and outside the canopy of the tree and at varying soil depths in Sofi district, Harari Region Ethiopia. Accordingly, twelve trees (six for each) isolated and nearly similar M. indica and Z. spina-christi trees in crop field growing on more or less similar site conditions, management practices, canopy coverage and height were selected. Soil samples were collected from under the canopy of trees, edge of canopy, outside of the canopy (10 m from the trees in crop field) and three soil depth; 0-20 cm, 20-40 cm and 40-60 cm for analysis of selected soil physical and chemical properties. The result of the study revealed that lower soil bulk density was observed under trees canopy and surface soil of both tree species than open field and subsurface soil ($p<0.01$), While soil water content at FC, PWP and AWHC were significantly ($p<0.01$) higher on subsurface than surface soil and under canopy of trees than open fields. However, no significant differences were observed in the texture and pH of soil ($p>0.05$). Soil EC, SOC, SCS, TN, AP and CEC were significantly ($p<0.01$) higher under the trees canopy than open field and on the surface than subsurface soil for both trees species in sorghum field. It can be concluded that these tree species have the potential to improve soil fertility and moisture beneath their canopy. Thus, the finding suggests that retaining these important trees species with proper management on farmland improve and maintain soil fertility and reduce chemical fertilizer amendments.

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INTRODUCTION

Climate change, soil erosion, overgrazing, deforestation, loss of biodiversity, degradation and desertification, high chemical fertilizer input and fast-tracked soil fertility loss are also becoming challenging factor to sustainable agricultural land productivity and wide environmental problems in Ethiopia (Alayu *et al.*, 2021). To tackle the multifaceted challenges in the areas, where the problem is very pressing is adopting agroforestry). Trees in agroforestry systems is capable of enhancing the microclimatic condition by decreasing temperature, evaporating, improving soil moisture, and serving as a filter to provide a buffer against direct sunlight (Kumar, 2016). Parkland agroforestry practices facilitate tighter nutrient cycling than monoculture systems, and enrich the soil with nutrients and organic matter, while improving soil structural properties Available P, soil organic carbon, K, Mg and total N of soils were higher under *Ficus vasta* and *Albizia gummifera* canopies compared to the contents in open fields and enhanced higher soil nutrient concentration under tree canopies than in open fields without trees (Zebene, 2016).

Scattered trees on farms characterize a large part of the Ethiopian agricultural landscapes today, while

tree species differ depending on their agro-ecological suitability such as rainfall, altitude, and soil and natural distribution patterns (Desta *et al.,* 2018). Therefore, investigation of the biophysical interactions of trees and crops under different ecological settings is vital to properly managing farm trees or sustaining the system. In the Harari Region, *Mangifera indica* and *Ziziphus spina-christi* is grown with annual crops dominantly in the central and lower parts of the Erer River basins including in the Sofi district and vicinities of Harar city (Tewodros *et al.,* 2015). However, scientific information on their effect on soils in farmlands is not well studied in the eastern part of the country including Harari Region.

Therefore, this study investigated the effect of parkland *Ziziphus spina-christi* and *Mangifera indica* trees on some selected physical and chemical properties of the soil under and outside the tree canopy as compared to the control on open sites. The results will be useful to farmers and other stakeholders to give insight into the effects of parkland trees on soil fertility in their farmlands. Therefore, to promote agroforestry trees on farmland, their compatibility with annual crops are important to generate information on the effect of these scattered tree species on soil condition. The objective of this study was to evaluate the effects of *Ziziphus spina-christi* and *Mangifera indica* trees on selected physicochemical properties of soil at different distances from the trees and soil depths in parkland agroforestry practice.

MATERIALS AND METHODS

Description of the Study Area

This research was conducted in Kile and Harawe kebeles of Sofi District, Harari Region, Ethiopia. The study site is found 545 km away from Addis Ababa, capital city of Ethiopia and 20km from Harar which is the capital city of Harari People Regional State. The study area is located, with an elevation range of 1300–1600 m.a.s.l. Based on 10 years of climate data (2012 to 2021), the mean minimum and maximum annual air temperatures of the area are 15 °C and 31 °C, respectively, with mean annual air temperature of 23 °C. In the Sofi district, the rainfall ranges from 630 to 810 mm. In the Sofi District medium textured sandy clay loam and sandy loam is dominant and rated as slightly to moderate alkaline with good permeability soils. The dominant soil type in the study area is Luvisols with the dominant soil texture of sandy clay loam, which is grayish in color.

Selection of the Study Sites and Trees

Then two rural kebeles, namely Kile and Harawe were purposively selected based on the potential existence of the selected trees species on farmland. Two tree species *(Ziziphus spina-christi* and *Mangifera indica)* were purposively selected because they are dominantly grown tree species along with annual crops and were already adapted in the study area. Six isolated and nearly identical individual *Z. spina-christi and M. indica* have approximately similar canopy width, management history, age, height, diameter at breast height and slope similarity were selected from the target study sites. The twelve trees (six for both tree species) were considered as replications.

Soil sampling

Soil samples were taken in four directions from the trees at three horizontal distances; under the tree canopy, edge of the canopy, and out of the canopy (10 m) in open area inside the farm field and at three soil depths; 0-20 cm, 20-40 cm and 40-60 cm using auger. These depths were selected because it is the soil depth where fine root of tree and crops dominate and consequently intense interaction is expected between the trees and crops grown on the same land management unit. The arrangement of treatments were: 2 tree species x 3 lateral distance x 3 soil depth x 6 replication (a total of 108 soil samples) combinations were used for this study. Additionally, from each horizontal distances and soil depths, undisturbed soil samples were collected for bulk density determination.

Soil Laboratory Analysis

Soil samples were analyzed at Batu Soil Research Center. Soil texture was determined by Bouyoucos hydrometer method. Bulk density was determined from undisturbed soil samples by calculated as the ratio of mass of oven dried soil (g) to the volume of the sampling core in cm^3. The soil-water retention capacity of the soil at field capacity (FC; at -0.33 bar) and at permanent wilting point (PWP; at -15 bars) was measured with the pressure plate apparatus while available water holding capacity was obtained by subtracting PWP from FC. The pH (pH-H_2O) of the soil was measured by potentiometer method, using soil water suspension. Electrical conductivity was determined in supernatant of soil-water suspension in the ratio of 1:2.5 by using Conductometric method. Total Nitrogen (%) was measured titrimetrically following the Kjeldahl digestion, distillation and titration method. Available phosphorus (AP) was determined following the Olsen extraction method. Cation exchange capacity (CEC) (cmol $_{(+)}$/kg of the soil was determined from ammonium acetate saturated sample by repeated washing with alcohol. Soil organic carbon (%) was estimated by the wet oxidation method. Soil organic carbon stock at the selected depths was calculated to determine soil

organic carbon storage of soils under the canopy of *Mangifera indica* and *Ziziphus spina-christi* using soil carbon stock conversion (FAO, 2019).

Statistical Analysis

The statistical differences between the values for the various parameters of distance from trees and soil depth were tested using analysis of variance (ANOVA) following the General Linear Model procedure of Statistical Analysis System (SAS) version 9.2. Moreover, least significant difference (LSD) test (P < 0.05 was used to compare and separate for significant means.

RESULTS AND DISCUSSION

Effects of *Ziziphus spina-christi* and *Mangifera indica* Trees on Soil Physical Properties

Soil texture

The results indicated that soil particle fractions of sand, silt and clay were not significantly varied (p > 0.05) with distance from trunk of trees and depth of the soil for both *Ziziphus spina-christ* and *Mangifera indica* tree species in sorghum farmland. The soil texture class of the study site was sandy clay loam according to USDA textural classification with higher proportions of sand particles. There were no textural class differences among the depths from the surface to subsurface and in all radial distances from trees. The lack of textural class difference between surface and sub-surface soils under trees might be attributed to the similarity in parent material from which the soils had originated. Similar findings reported by Haile *et al*. (2019) indicated that soil particle fractions of clay, silt and sand did not significantly vary with distance from the *Z. spina-christi* tree trunk in sorghum field in Wollo, Ethiopia. The result is in agreement with those reported by(Alemayehu *et al.,* 2017; Desta *et al*., 2018; Muktar *et al*., 2018; Musa *et al*., 2020) and these also support that the soil texture in distance from trees and soil depth were more or less similar.

Bulk Density

Bulk density showed a highly significant difference (p < 0.01) with distance from *Mangifera indica* and *Ziziphus spina-christi* trees trunk and soil depth (Table 1). Highest mean value of bulk density (BD) was observed on 40-60 cm soil layer in open field, whereas the lowest value was observed in the surface soil (0-20 cm) of the under of canopy for both tree species (Table 1).

Table 1. Mean values (± SD) of soil bulk density at different radial distances from trees trunk, soil depths and their interaction effect in the study area.

Treatments		*Mangifera indica*	*Ziziphus spina-christi*
Distances	Depths (cm)	BD (g/cm^3)	BD (g/cm^3)
Under Canopy	0-20	1.21^{g}±0.14	1.13^{e}±0.03
	20-40	1.24^{ef}±0.13	1.20^{cd}±0.05
	40-60	1.31^{c}±0.14	1.33^{b}±0.07
Edge of Canopy	0-20	1.23^{f}±0.13	1.17de±0.04
	20-40	1.25^{de}±0.14	1.23^{cd}±0.07
	40-60	1.36^{b}±0.13	1.40^{a}±0.08
Out of Canopy	0-20	1.24^{ef}±0.13	1.22^{cd}±0.08
	20-40	1.26^{d}±0.14	1.26^{c}±0.07
	40-60	1.39^{a}±0.13	1.45^{a}±0.08
	LSD (5%)	0.014	0.058

* Means with the same letter are not significantly different (P< 0.05). BD=Bulk density

The decreasing trend of bulk density near trees might be attributed to low compaction, and high soil organic inputs including from vesicular-arbuscular mycorrhizal fungi that can bind soil particles into aggregates under the trees than open field resulting in structural stability and desirable pore size distribution. The higher soil BD recorded in subsurface soil than surface soil might be due to declining of SOM both with the increasing soil depth. This is in line with the study, Salimath *et al*. (2022) reported that the improvement in bulk density of soil in mango with cowpea farmland due to increasing the soil organic matter by the accumulation of biomass from intercrops. Similar to the current study, lower bulk densities were observed under isolated *Z. spina-christi* in sorghum field (Haile *et al*., 2019).

Soil Water Content and Retention Capacity

The ANOVA revealed that soil water contents at FC, PWP and AWHC were highly significantly ($P < 0.01$) affected by radial distance from trees trunk, soil depth and their interactions (Table 2) for both *M. indica* and *Z. spina-christi* tree species in a sorghum field. The decreasing trend of soil water content at field capacity (FC), permanent wilting point (PWP), and available water holding capacity (AWHC) of soil with distance from trees increase, and increased with soil depth increase. The finding of the study implies that soil water content at FC, PWP and AWHC was influenced by the presence of trees in sorghum farmland.

Table 2. Mean values (± SD) of soil FC, PWP, and AWHC at different radial distances from trees trunk, soil depths and their interaction effect.

	Treatments		Soil parameters		
Trees	Distances	Depths (cm)	FC (%)	PWP (%)	AWHC (%)
M. indica	Under Canopy	0-20	17.61^{d}±1.07	10.20^{c}±1.08	7.41^{ab}±0.19
		20-40	19.98^{b}±1.04	12.40^{b}±1.11	7.57^{a}±0.24
		40-60	21.91^{a}±1.09	14.23^{a}±1.13	7.68^{a}±0.26
	Edge of canopy	0-20	15.76^{e}±1.41	8.35^{d}±1.48	7.41^{ab}±0.46
		20-40	17.79^{cd}±1.53	10.31^{c}±1.21	7.48^{ab}±0.14
		40-60	18.06^{c}±1.60	10.47^{c}±1.34	7.59^{a}±0.25
	Out of Canopy	0-20	13.41^{h}±1.42	7.16^{f}±1.12	6.25^{d}±0.41
		20-40	14.21^{g}±1.47	7.17^{f}±1.64	7.04^{c}±0.25
		40-60	15.11^{f}±1.09	7.92^{e}±1.39	7.19^{bc}±0.33
	LSD (5%)		0.375	0.305	0.307
Z. spina-christi	Under Canopy	0-20	16.59^{d}±1.58	9.58^{c}±1.28	7.01^{a}±0.42
		20-40	17.82^{b}±1.69	10.44^{ab}±1.23	7.37^{a}±0.39
		40-60	18.74^{a}±1.95	11.12^{a}±1.49	7.62^{a}±0.43
	Edge of canopy	0-20	14.57^{f}±1.47	7.57^{de}±1.30	7.01^{a}±0.20
		20-40	15.59^{e}±1.78	8.28^{d}±1.18	7.31^{a}±0.21
		40-60	17.12^{c}±1.85	9.74^{bc}±1.21	7.39^{a}±0.17
	Out of Canopy	0-20	12.39^{h}±1.71	6.59^{ef}±1.08	5.80^{c}±0.52
		20-40	12.80^{h}±1.66	6.71^{f}±1.04	6.09^{bc}±0.33
		40-60	13.74^{g} ±1.76	6.92^{f}±1.03	6.82^{ab}±0.39
	LSD (5%)		0.478	0.792	0.829

* Means with the same letter are not significantly different ($P< 0.05$).

The soil organic matter of under canopy of trees were the highest and its BD was the lowest, which contributes to higher water content at FC, PWP and AWHC. Similarly, Desalegn and Zebene (2017) reported that soil moisture was highly significantly higher under canopy zone of *Croton macrostachyus* than outside of canopy in farmland. The reason for the highest mean value of water content recorded for near trees at subsurface soil might be due to high amount of clay which absorb water in clay colloidal particle. Similarly, Wakene (2001) reported that the highest and the lowest soil water content at FC PWP and AWHC were observed in the deeper subsoil (90-140 cm) layer of the open cultivated field and the surface (0-16 cm) soil layer of the abandoned research field respectively. This study is also in line with Yang *et al*. (2016) higher soil water content under and edge of canopy of *Z.spina-christi* than outside of the canopy.

Effect of *Ziziphus spina-christi* and *Mangifera indica* Trees on Soil Chemical Properties

Soil reaction (pH)

Soil pH (H_2O) was not significantly ($P> 0.05$) affected by radial distance from *M. indica* and *Z. spina-christi and soil* depth (Table 3). The result indicated that soil pH a slightly decrease as distances from the trees and soil depth increase in parkland agroforestry practice (Table 3).

Table 3. Mean values (± SD) of soil pH and electrical conductivity at different radial distance from tree trunk, soil depths and their interaction effect in the study area.

Treatments		*Mangifera indica*		*Ziziphus spina-christi*	
Distances	Depths(cm)	pH (H_20)	EC (dSm^{-1})	pH (H_20)	EC (dSm^{-1})
Under Canopy	0-20	$7.92^{a}\pm0.21$	$0.22^{a}\pm0.05$	$7.93^{a}\pm0.22$	$0.24^{a}\pm0.05$
	20-40	$7.91^{a}\pm0.21$	$0.18^{bc}\pm0.07$	$7.92^{a}\pm0.21$	$0.19^{b}\pm0.04$
	40-60	$7.90^{a}\pm0.10$	$0.11^{d}\pm0.06$	$7.91^{a}\pm0.10$	$0.12^{d}\pm0.04$
Edge of Canopy	0-20	$7.83^{a}\pm0.16$	$0.20^{ab}\pm0.06$	$7.88^{a}\pm0.15$	$0.24^{a}\pm0.05$
	20-40	$7.80^{a}\pm0.15$	$0.17^{c}\pm0.07$	$7.86^{a}\pm0.15$	$0.18^{c}\pm0.05$
	40-60	$7.82^{a}\pm0.12$	$0.11^{d}\pm0.06$	$7.82^{a}\pm0.16$	$0.12^{d}\pm0.04$
Out of Canopy	0-20	$7.92^{a}\pm0.21$	$0.16^{c}\pm0.02$	$7.83^{a}\pm0.17$	$0.19^{b}\pm0.05$
	20-40	$7.91^{a}\pm0.21$	$0.12^{d}\pm0.05$	$7.81^{a}\pm0.16$	$0.12^{d}\pm0.05$
	40-60	$7.90^{a}\pm0.10$	$0.08^{e}\pm0.06$	$7.83^{a}\pm0.12$	$0.08^{e}\pm0.04$
	LSD (5%)	Ns	0.025	ns	0.005

* Means with the same letter are not significantly different (ns) ($P< 0.05$)

The high accumulation of litter under the tree canopy may result in increased amounts of organic matter in the soil, which may increase the CEC. The high levels of CEC under tree canopy might contribute to a relatively high value of pH than the open fields outside the influence of trees. The present finding was well going with the findings of Haile *et al.* (2019) who reported the surface, subsurface, and overall mean values of soil pH at all radial distances from *Z.spina-christi* tree trunks were not significantly influenced. Similarly, pH (H_2O) values of the soil samples taken from 0-20 cm and 20-40 cm soil layer under the canopy and outside of the canopy of Avocado (*Persea americana)* trees in maize farmland and there was no significant ($p>0.05$) difference between the soil depths (Mesfin *et al*., 2014). Contradicting this finding, Kumari *et al.* (2020) reported that variation in soil pH was quite inconsistent throughout the soil profile (0–60 cm depth) in mango intercropping with annual crops and surface soil was attributed to slight acidic behavior and subsequent increase in pH was found with depth.

Electrical conductivity (EC)

The ANOVA revealed that soil EC was highly significantly ($P<0.01$) affected by distance from the trees trunk and soil depth in sorghum field (Table 3). Relatively, higher soil electrical conductivity under trees canopy as compared to soils outside canopy might be due to the relatively higher leaf biomass, which upon decomposition release soluble nutrients to the soil. This also might be due to the increased accumulation of aboveground biomass and associated cation uptake by the tree species (Musa *et al.,* 2020*)*. Following this result, electrical conductivity of soil was increased in mango with cowpea and French bean within 0-15cm and 15-30 cm of soil depth, increase in the soil organic matter attributes to increasing microbial activities in the soil which might have improved the soil electrical conductivity (Swain *et al.,* 2012). The present result disagreed with Haile *et al.* (2019) who reported non-significant effects of *Ziziphus spina-christi* over EC at the arid areas of Hibru districts of Ethiopia.

Total nitrogen

The total nitrogen (TN) content of soils was highly significantly ($P \leq 0.01$) affected by distance from tree species, soil depth and their interaction effects (Table 4). The TN result was highest under canopy and lowest outside of the canopy of both *Mangifera indica* and *Ziziphus spina-christi* trees in sorghum farmland (Table 4).

Table 4. Mean values (± SD) of soil TN, AP and CEC at different radial distances from trees trunk, soil depths and their interaction effect in the study area.

Treatments	Treatments				Soil parameters
Trees	Distances	Depths(cm)	TN (%)	AP (ppm)	CEC(cmol (+)/kg)
M. indica	Under canopy	0-20	$0.23^{a}\pm0.06$	$10.16^{a}\pm0.71$	$25.57^{a}\pm1.69$
		20-40	$0.17^{c}\pm0.05$	$8.17^{b}\pm0.51$	$21.76^{d}\pm1.81$
		40-60	$0.14^{e}\pm0.05$	$6.91^{c}\pm0.51$	$19.26^{e}\pm1.66$

	Edge of canopy	0-20	$0.22^{b}\pm0.05$	$8.56^{b}\pm0.51$	$24.18^{b}\pm1.54$
		20-40	$0.15^{d}\pm0.06$	$7.12^{c}\pm0.51$	$21.51^{d}\pm1.72$
		40-60	$0.12^{f}\pm0.05$	$6.17^{d}\pm0.51$	$18.43^{f}\pm1.66$
	Out of canopy	0-20	$0.14^{e}\pm0.05$	$6.42^{d}\pm0.52$	$22.39^{c}\pm1.61$
		20-40	$0.14^{e}\pm0.06$	$5.50^{e}\pm0.51$	$19.02^{e}\pm1.66$
		40-60	$0.09^{g}\pm0.05$	$4.81^{f}\pm0.61$	$16.70^{g}\pm1.40$
		LSD (5%)	0.006	0.410	0.422
Z. spina-christi	Under canopy	0-20	$0.30^{a}\pm0.05$	$10.54^{a}\pm1.36$	$26.64^{a}\pm0.99$
		20-40	$0.20^{b}\pm0.05$	$8.56^{b}\pm1.66$	$23.62^{b}\pm1.08$
		40-60	$0.13^{de}\pm0.05$	$7.30^{c}\pm1.66$	$18.76^{de}\pm0.87$
	Edge of canopy	0-20	$0.27^{a}\pm0.06$	$8.95^{b}\pm1.66$	$26.44^{a}\pm1.28$
		20-40	$0.18^{bc}\pm0.06$	$7.52^{c}\pm1.66$	$23.48^{bc}\pm1.21$
		40-60	$0.09^{ef}\pm0.05$	$6.56^{d}\pm1.66$	$18.23^{e}\pm1.12$
	Out of canopy	0-20	$0.12d^{ef}\pm0.05$	$7.28^{c}\pm1.66$	$22.48^{c}\pm1.08$
		20-40	$0.14^{cd}\pm0.03$	$6.35^{d}\pm1.66$	$19.46^{d}\pm1.23$
		40-60	$0.07^{f}\pm0.04$	$3.47^{e}\pm0.5$	$18.10^{e}\pm1.14$
		LSD (5%)	0.047	0.519	1.048

* Means with the same letter are not significantly different (P<0.05)

Generally, soil total nitrogen (TN) decreased with increasing distance from the tree trunk and soil depths. This is probably due to the accumulation of higher organic matter through leaf litter fall and deep rooted nature of a trees can take up nutrients from deepest soil profile. Droppings of animals resting under the trees and birds could also be responsible for the higher total nitrogen observed under the trees canopy. Soil TN was higher under the edge of the canopy of *Z.spina-christi*) then outside of the canopy on the wheat farm (Yang *et al*., 2016). This finding is in agreement with previous studies in different sites, where Fischer *et al*. (2012) reported that soil total nitrogen was higher under canopy of mango than open field (9m from the tree); all these differences were pronounced in the 0-20 cm layer than in 10 -30 cm, indicating positive influence from mango litter. In contrast to this study, Fentahun (2008) observed no change in total nitrogen under canopy of *Ziziphus spina-christi* trees as compared to away from the tree canopy area in the western Amhara region, Ethiopia.

Available phosphorus

The available phosphorus (AP) was highly significantly ($P \leq 0.01$) affected by horizontal distance from both *M. indica* and *Z. spina-christi* trees species in sorghum field and soil depth (Table 4). The content of available phosphorus (AP) under the trees canopy appeared to be significantly higher than outside of canopies. Considering the three soil depths, the mean values of AP at 0-20 cm soil depth were significantly higher than 20-40 cm and 40-60 cm soil depth at all radial distances for both tree species (Table 4). Available phosphorus was significantly affected by presence of the trees in a sorghum field in a parkland agroforestry practice. This might be due to the higher organic matter under tree species boosting soil microbial activity. The current result agrees with the result reported for *Ziziphus spina-christi* which revealed higher significant in AP under canopy than out of canopy of trees in sorghum field from Northern Ethiopia (Haile *et al*., 2019). An increasing in available phosphorus due to higher organic matter percentage was observed under mango with better soil health improvement under intercropped with pigeon pea (Murmu *et al*., 2018).

Cation Exchange Capacity (CEC)

The current study showed that the mean value of soil CEC across soil depth and radial distances from trees trunk were highly significantly different ($p < 0.01$) for both *M. indica* and *Z. spina-christi* tree species in a sorghum field (Table 4). The values of CEC decreased as soil depth and distance from trees canopy increase (Table 4). This could be mainly due to high organic matter accumulation under the tree canopy than in the open fields implying the release of more cations to the soil through mineralization. Mesfin *et al*. (2014) also reported that soil CEC decreasing trend with increasing depth and distance from tree trunks which might be due to organic matter deposition under a canopy of *Persea americana* and increasing biological activity that enhances organic matter decomposition and subsequent mineralization. In harmony with this study, significantly higher soil CEC

under canopy than outside canopy in parkland agroforestry were reported for *F.vasta* (Zebene, 2016), for *A.senegal* (Alemayehu *et al*., 2017), *C. africana* and *C. macrostachyus* (Muktar *et al*., 2018), for *A. tortolis* (Desta *et al.,* 2018) in different parts of Ethiopia. The high CEC on the surface of the under a canopy of trees might be due to high clay and colloidal contents of SOM that can absorb and hold positively charged ions.

Soil organic carbon

Differences were highly significant ($p<0.01$) among radial distance from *M. indica* and *Z. spina-christi* in sorghum field and soil depths for soil organic carbon (SOC) (Table 5). The result revealed that higher soil organic carbon levels by 40% and 49% under the canopies of *M. indica* and *Z. spina-christi* than outside canopy respectively, in parkland of sorghum field. The soil organic carbon was decreased as soil depth increased (Table 5).

Table 5. Mean values (± SD) of SOC and SCS as influenced by radial distance from trees, soil depth and interaction effect at study the area

Treatments		*Mangifera indica*		*Ziziphus spina-christi*	
Distances	Depths(cm)	SOC (%)	SCS (Mg ha^{-1})	SOC (%)	SCS (Mg ha^{-1})
Under Canopy	0-20	3.29^{a}±0.21	7.73^{a}±1.68	3.54^{a}±0.21	7.77^{a}±1.49
	20-40	2.44^{c}±0.22	5..88^{c}±1.27	2.81^{b}±0.11	6.53^{b}±1.36
	40-60	1.95^{d}±0.22	4.95^{d}±1.18	2.22^{d}±0.23	5.75^{c}±1.44
Edge of Canopy	0-20	3.09^{b}±0.13	7.40^{b}±1.53	2.92^{b}±0.13	6.66^{b}±0.6
	20-40	1.95^{d}±0.24	4.75^{de}±1.31	2.35^{c}±0.21	5.57^{c}±1.75
	40-60	1.61^{f}±0.19	4.27^{f}±0.70	1.83^{f}±0.17	4.97^{d}±1.01
Out of Canopy	0-20	2.01^{d}±0.16	4.85^{de}±1.06	2.42^{c}±0.12	5.76^{c}±1.25
	20-40	1.85^{e}±0.24	4.55^{ef}±0.51	2.04^{e}±0.16	4.98^{d}±1.14
	40-60	1.61^{f}±0.17	4.38^{f}±0.80	1.30^{g}±0.15	3.64^{e}±0.96
	LSD (5%)	0.091	0.292	0.121	0.334

* Means with the same letter are not significantly different ($P<0.05$). SCS= Soil organic carbon stock

The attribute of higher organic carbon content under the tree canopies might have resulted from high leaf litter fall, and decomposition of dead roots from the tree as compared to the adjacent open areas. Similarly, fruits on branches of *Z. spina-christi* and *M. indica* were commonly consumed by birds and human beings and unused part fruits dropped on the soil, and bird droppings and the presence of integrated livestock and their dung deposition when resting under trees shade during the off-season might be contributing to higher soil organic carbon concentration. The present finding is in agreement with the observation of Yang *et al*. (2016) who had higher SOC under the edge of the canopy of *Z.spina-christi* than outside of the canopy in the wheat farm. Gebremedhn *et al*., 2018) also reported that the SOC significantly decreased with increasing depth and distance from the *Z. spina-christi* crown in the sorghum field. Soil organic matter was found that were better than in the control plot where no mango trees were planted and decreased with soil depth in parkland agroforestry in southern parts of Bangladesh (Rana, 2022).

Soil organic carbon stock

Soil organic carbon stock was a highly significant ($p<0.01$) different between the distance from the trees trunk and soil depth (Table 5). Soil carbon stock was increased by 39.3% and 34.6% under the canopies of *M. indica* and *Z. spina-christi* tree species, respectively, than in an open field. The overall mean value of SOC stock in surface soil depth was significantly higher than subsurface soil depth at all radial distances from both tree species. This may be associated with the accumulation of high litter from both above and below-ground tree biomass and the supply of more organic fertilizer from trees. This finding is in agreement with previous studies, where Fischer *et al*., (2012) also reported that SOC stock decreased with increasing from the Mango tree trunk and showed a significant difference($p<0.05$) in 0.5 m, 2 m and 9 m distance from the mango trees in crop field. *Mangifera indica* has immense potential in carbon retention and great potentiality to retain the organic carbon in the soil as compared to open fields of annual crops and this organic carbon stock has great potentiality to improve crop productivity (Naik *et al*. 2017). Trees in parkland agroforestry practices are believed to sequester more carbon under the canopy than in open fields (outside of the canopy) because tree incorporation in croplands would bring in higher carbon storage above and belowground.

CONCLUSIONS and RECOMMENDATIONS

The result of the study revealed that soil water content at FC, PWP, AWHC, EC, SOC, SCS, TN, AP, and CEC was significantly higher under the canopy of the tree as compared to the open field. Bulk density increased with increasing distance from the

tree trunk and soil depths. While soil particles (sand, silt, and clay) distribution and pH were significantly not influenced by the presence of scattered *M.indica* and *Z. spina-christi* trees. Moreover, the selected soil physicochemical improvement under trees might be brought through the accumulation of SOM; high leaf litter fall, decomposition of dead roots from the tree, bird droppings, and the presence of integrated livestock and their dung deposition when resting under trees shade during the off-season, reduction in the leaching losses of nutrients and cumulative effects of nutrient recycling by litter from trees. Therefore, parkland agroforestry practices involving *M.indica* and *Z.spina-christi* can be used as an economically feasible, environmentally friendly, and sustainable alternative to maintaining soil fertility to resource-poor farmers in similar agro ecological conditions. In addition to their role in improving soil fertility, these two tree species provide various products and services to the community. Thus, retaining these important trees species on farmland with proper management practices improve the food security of small holders and reduce chemical fertilizer amendments.

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